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DOMINION OF CANADA—DEPARTMENT OF AGRICULTURE

Soil Moisture and Crop Production under Dry Land Conditions in Western Canada

by

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EXPERIMENTAL FARMS BRANCH

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SOIL MOISTURE AND CROP PRODUCTION

INTRODUCTION

The frequent occurrence of severe droughts over extensive areas in Western Canada has drawn attention to the need of definite information on the use and the conservation of soil moisture. This bulletin presents the results of twelve years' study of soil moisture problems conducted by the Division of Field Husbandry of the Central Experimental Farm, Ottawa, at the branch farm located at Swift Current, Saskatchewan. The results to date indicate that the most feasible method of partially counteracting the effects of drought lies in improved methods of crop production whereby better use can be made of the available moisture, and whereby part of the annual loss can be prevented. These results are in keeping with work conducted by investigators in other countries where similar climatic conditions prevail.

The subject matter of this bulletin deals in general with the open plains area of Manitoba, Saskatchewan, and Alberta, and especially southwestern Saskatchewan and southeastern Alberta where climatic conditions are similar to those of Swift Current. These conditions are low rainfall, low relative humidity, and high evaporation. The cultivated land in this area has been devoted chiefly to the growing of wheat, which, owing to these climatic factors, is generally of a high quality.

The cultural practices followed on the prairies of Western Canada are similar to those of other prairie countries where the climate is similar. Wheat is generally raised year after year without the inclusion of another crop or the regular application of fertilizer of any kind. At frequent intervals the land is summer-fallowed, that is, cultivated for one season but not seeded, so that weeds can be controlled and moisture conserved for the following crop. The first crop following such treatment is called a " summer-fallow crop," while a crop on land that produced a crop the previous season is called a " stubble crop "; these terms will be used in this bulletin. The important difference between a summer-fallow crop and a stubble crop is that the former usually has more moisture available for crop production. The stubble crop is subjected to more hazardous conditions and generally returns a lower yield.

PRECIPITATION AND SOIL MOISTURE

Precipitation records include the water that falls as rain and the snowfall reported as its equivalent in water. The total precipitation varies between rather wide limits for any given locality, and may vary widely within a comparatively small area. The average precipitation for 50 years at Swift Current is 15·31 inches, with a high mark of 24·55 in 1891 and a low of 9·66 in 1894 (Fig. 1). The average rainfall for the months of April, May, June, and July for the same period is 8·07 inches. Seasonal variations in areas of low rainfall generally have a greater effect on crop production than in areas of more ample moisture.

The seasonal distribution of rainfall in the Prairie Provinces aids in crop production, for a large portion falls during the months of May, June, and July when crop growth is most rapid. The average monthly precipitation at Swift Current in shown in Fig. 2. The monthly distribution at Ottawa, Ontario, is included for the purpose of comparison.

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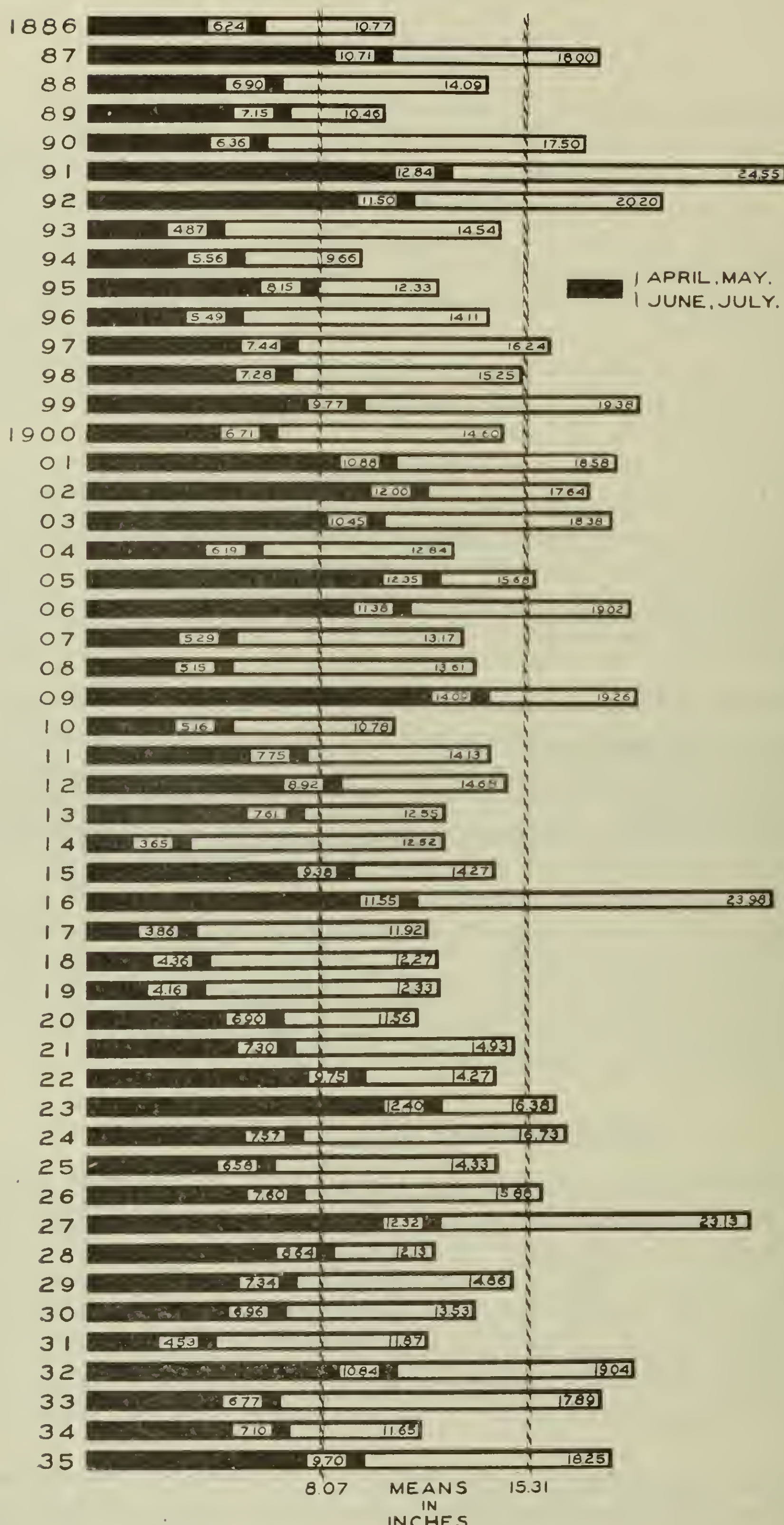
PRECIPITATION AT SWIFT CURRENT
50 YEARS 1886-1935



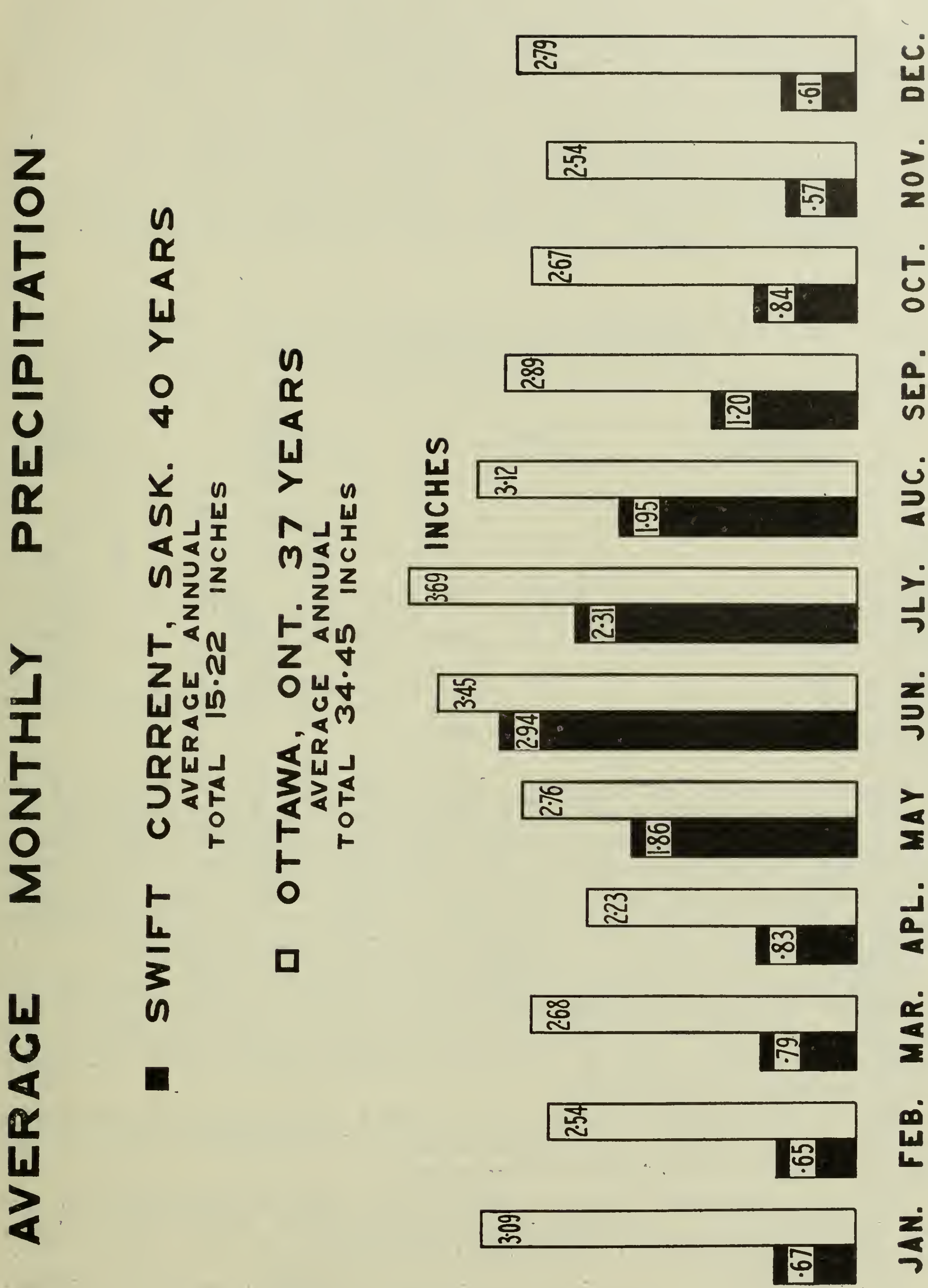


Fig. 2.—Average monthly precipitation.

An analysis of the rainfall at Swift Current during the months of April to October, inclusive, for the years 1922 to 1934 is given in Table 1. This table shows the frequency and intensity of rainfall measured during the 24-hour periods. Fifteen heavy showers of short duration are included in the daily records of 0·76 inches or over. Five of these showers contained hail which was destructive on two occasions. During periods of very heavy rainfall there is generally considerable loss owing to run-off, this being influenced by the class of soil and the lay of the land. Showers of one-quarter inch or less, which moisten only a shallow layer of surface soil, have, as a rule, no appreciable effect on crop growth. This moisture is generally lost within a day or two by evaporation. A shower following a heavy rain while the soil is still moist is generally of more value than an equal amount of rain when the surface 4 to 5 inches of soil are dry.

TABLE 1—RAINFALL FREQUENCY AND INTENSITY AT SWIFT CURRENT, SASK. APRIL-OCTOBER, 1922–1934: 2,782 DAYS*

Daily Precipitation	Times occurring	Daily Precipitation	Times occurring
(inches)		(inches)	
0·01–0·10	511	0·41–0·50	22
0·11–0·20	115	0·51–0·75	36
0·21–0·30	77	0·76–1·00	25
0·31–0·40	33	1·00–	20

* Number of days without measurable rainfall—1943.

Rainfall is caused by the cooling of the atmosphere, thus causing the water vapour present to condense and fall as rain or snow. A heavy rainfall, therefore, depends on the presence of warm, moisture-laden winds which yield a large quantity of moisture when cooled. The geographical location of the western plains tends to prevent the presence of such winds, because mountain barriers and the distance from large bodies of water where rapid evaporation is taking place both reduce the moisture carried by the atmosphere.

Local evaporation from the surface of small bodies of water and from the soil, together with moisture given off by plants, adds to the water vapour in the atmosphere. This amount is generally too small to have any real effect on the rainfall of the district, especially when the prevailing winds are low in moisture content and high in temperature.

There is no evidence in the weather records to indicate that the country is gradually becoming drier, when considered over a long period of years, or that there are definite cycles of wet and dry years.

From the standpoint of crop production, the value of precipitation in any form depends on the amount which penetrates the soil. This water is designated in this bulletin by the term "soil moisture."

The soil moisture varies from day to day, depending on climatic factors and plant growth. In Western Canada, where the annual rainfall varies from 13 to 20 inches as compared with 25 to 40 inches in Eastern Canada (Fig. 3), the conservation of soil moisture becomes a vital problem, and special tillage methods are necessary. These methods are grouped under the general heading

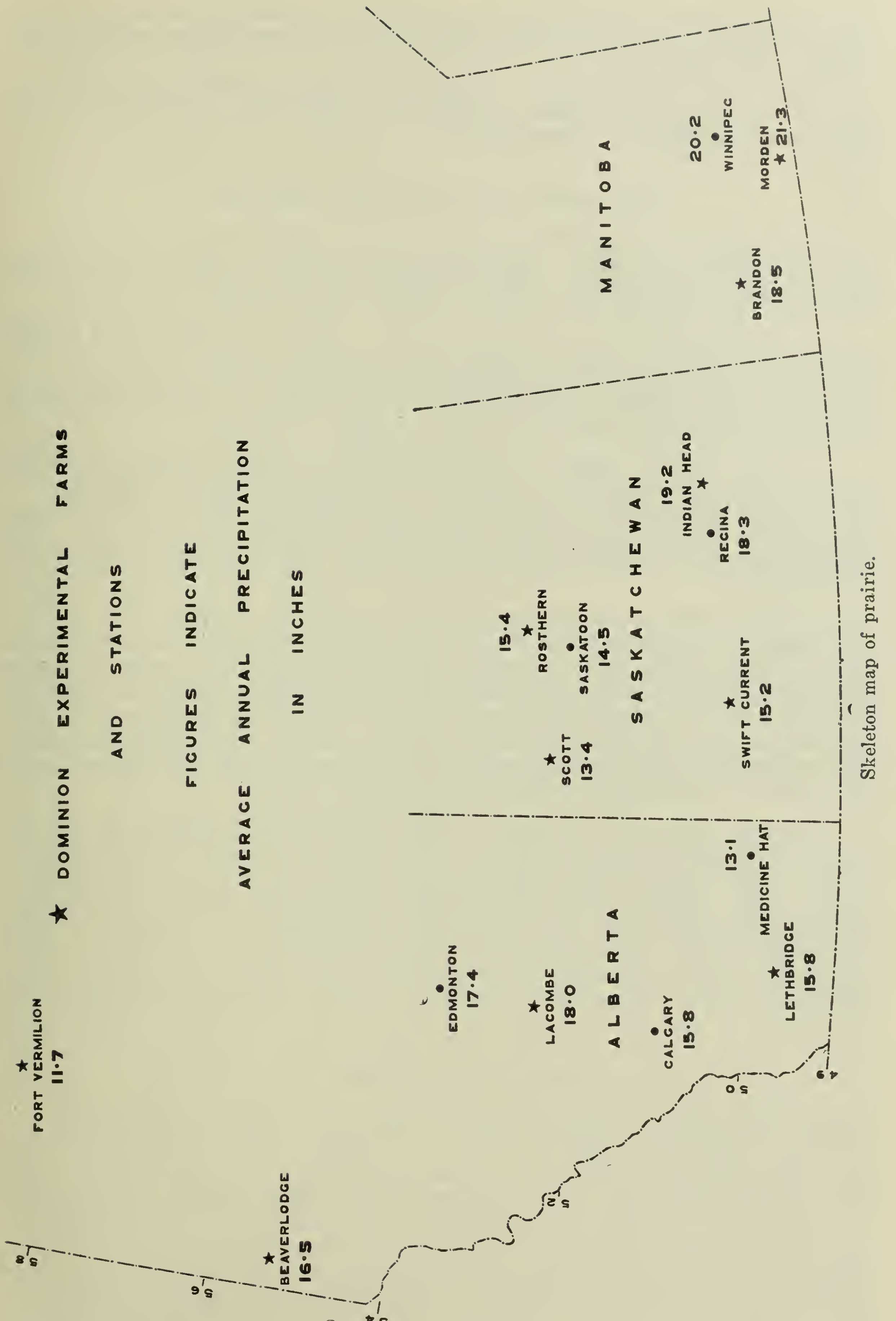


FIG. 3.—Average annual precipitation at the Dominion Experimental Farms and Stations located in the Prairie Provinces.

of "Dry Farming," which implies the use of the summer-fallow for the storage of soil moisture. In seasons of low rainfall even these methods may not guarantee a profitable crop.

The yearly fluctuations in precipitation make it necessary for the agriculturist to plan his operations so that he can make the most effective use of the rainfall, irrespective of the season.

ABSORPTION OF WATER BY THE SOIL

Soil moisture is divided into three classes, depending on the manner in which it is held in the soil. These divisions are more or less arbitrary, each form gradually merging into the other without a sharp line of division.

1. The fine particles or colloidal material of the soil holds a small amount of water which is known as hygroscopic moisture. The amount so held depends on the degree of saturation of the soil air and the amount of colloidal material. Such moisture does not move from particle to particle except by evaporation and condensation, and is of no value to the plant.

2. As the moisture content of the soil increases, the soil particles or granules are surrounded by thin films of water. These films gradually thicken, and the small spaces between the soil particles become filled with water. This is known as capillary moisture, and is the main source of supply for the plant. Such moisture will move slowly in any direction from a point of high to one of low concentration.

3. With a further increase in moisture, the larger pore spaces become filled and the water starts to move downward in response to the force of gravity. This is known as gravitational water. While the gravitational water is moving downward, each soil particle is saturated in respect to hygroscopic and capillary moisture. The downward movement continues until all the moisture is held by hygroscopic and capillary forces, or until the ground water table is reached. The rate of the downward movement is influenced by the class of soil, being rather slow in a clay soil and fairly rapid in a sandy soil.

A typical loam soil in Western Canada contains approximately 20 per cent of water when in a moist condition. Such soil would weigh around 84 pounds to the cubic foot, and would consist of 70 pounds of soil and 14 pounds of water. Cereal crops would quickly reduce the moisture content of such soil to 10 per cent or even less, which would be equivalent to the removal of about 7 pounds of water. Seven pounds of water over an area of one square foot is equivalent to a rainfall of 1·34 inches. It would require a rainfall of nearly 1½ inches, all to be absorbed by the soil, in order to restore the original moisture content of this soil to a depth of one foot. Below this point the soil would remain dry until more rain had fallen, while in the meantime some of the absorbed water would evaporate. Light showers may have little influence on soil moisture, particularly if their occurrence be at wide intervals, for the soil is moistened to only a shallow depth and moisture so held evaporates readily.

In one important respect western prairie soils differ very markedly from those of more humid sections. In some of the latter it is necessary to install tile drains in order to carry off excess water, which usually contains some valuable plant nutrients. Cropped land on the prairies may be moistened to a depth of a few inches only in the period between harvest and the following spring. Observations at Swift Current have shown this depth to vary from 9 to 30 inches according to the season. Even summer-fallowed land, which has been allowed to lie fallow for the express purpose of storing moisture, has not been moistened to a depth exceeding that ordinarily reached by the roots of spring seeded crops. The loss of soil fertility by leaching under such conditions is negligible.

So far this discussion has attached no significance to underground water which occurs at a greater or lesser depth throughout most of the prairies. Formerly, the opinion was widely held that such water moved upward through the soil by capillarity and could be used by crops. Capillary movement of water in the soil is undoubtedly important in conveying water to plant roots through short distances. However, this movement is limited and too slow in action to afford any real contribution of water from underground sources for the use of growing plants, unless the water table is within ten feet of the surface.[1]

In a few localized areas the contour and nature of the land is such that water occurs within a few feet of the surface. Under such conditions, deep-rooted plants are able to secure ample supplies of water. Over most of the prairie area underground water is located at too great a depth to be reached by the plant roots.

Changes in barometric pressure and temperature are probably accompanied by movements of soil air which carries considerable amounts of water in vapour form. A condensation of this vapour might conceivably result in moving water in the soil from one point to another, but evidence that underground water is moved in appreciable amounts by this process is meagre.

Studies conducted in Russia[2] and northern Africa indicate that moisture present as vapour in the atmosphere may be transferred to some extent to the soil as a result of temperature differences between soil and air. Appreciable increases in soil moisture as a result of this phenomenon have not been detected under the conditions prevailing at Swift Current.

The value of snow in adding to soil moisture appears to have been over-estimated, although under some conditions it is distinctly useful. Snow, from storms occurring early in the fall, usually melts quickly and the water enters the soil, but after the soil freezes no more water can enter. In the spring, there may be considerable loss of snow water by run-off, particularly if the snow thaws rapidly and the ground is frozen. The run-off cannot all be considered as lost, for part may accumulate in low areas where it penetrates the soil after the ground thaws. The benefit of such accumulation is generally apparent in the growth of crops in areas subject to spring flooding.

The proportion of rain received during the growing season which becomes available for crops cannot be determined readily, but a careful study of the various factors involved indicates that not more than one-half can be considered as effective or useful rain. The average rainfall during the growing period at Swift Current is only 8 inches. As one-half of this amount is not sufficient for the production of profitable crops, unless supplemented by a reserve in the soil at seeding time, the summer-fallow is employed to increase the reserve of moisture.

EXPERIMENTAL METHODS

Two distinct methods were used in the soil moisture investigations. In one case, samples of soil were collected from fields, and the percentage of moisture determined by drying and weighing. In the other case, water-tight tanks containing known quantities of soil were weighed at periodic intervals, and the moisture content calculated from the difference in weight.

The results secured from moisture determinations of soil samples taken in the field were not always as reliable as the results secured from the tank experiments. Variations in the physical properties of the soil as it occurred in the field exerted considerable influence on the moisture content, and thus introduced a large experimental error. The average results from a large number of samples would

[1] Hilgardia, Vol. 2, No. 11, 1927. Shaw, C. F. and Smith, A.
[2] Proc. Int. Cong. of Soils Science, Vol. 1, 1927, Lebedev, A. F.

tend to overcome this natural variability in the soil moisture content, but this method was inadvisable on account of the labour involved and the unavoidable damage to growing crops.

The figures in Table 2 are presented to show the variability in total moisture of soil samples obtained from an apparently uniform summer-fallow. The samples were taken to a depth of 4 feet, at 20 points, 18 inches apart. These

TABLE 2—VARIATIONS IN MOISTURE CONTENT OF SOIL SAMPLES COLLECTED FROM AN APPARENTLY UNIFORM SUMMER-FALLOW

Depth of Sampling	Total Moisture		
	Highest	Lowest	Average
	%	%	%
0–6 inches	18·5	13·0	15·06
6–12 inches	16·8	13·6	15·29
12–24 inches	17·8	14·3	15·51
24–36 inches	18·2	15·0	16·80
36–48 inches	17·5	12·2	15·23

figures show the highest and lowest moisture contents of the samples obtained at the different depths. The greatest variation was from 13·0 to 18·5 per cent, and the smallest from 15·0 to 18·2 per cent.

In two series, each of 100 samples, taken on summer-fallowed land to a depth of 12 inches, at 12-inch intervals, there was a range in one case of 10·4 to 17·6 per cent of moisture, and in the other from 12·3 to 19·1 per cent. Several hundred soil samples have also been taken from plots, both on the Swift Current Station and on the other prairie farms and stations of the Dominion Experimental Farms System, on light and heavy soils. It is apparent from the results of this work that, in the estimation of moisture changes by means of soil samples, the figures are only comparable with crop yields after a generous allowance has been made for the probable error.

The use of tanks served as a more reliable and convenient method for determining the changes in total moisture content of the soil throughout the year. The tanks were made of galvanized iron, and were 15 inches in diameter and 5 feet in depth. They were set in pits so that the top of the soil in the tank was approximately at ground level. The tanks used in each experiment were filled with uniform, well-mixed soil which was placed in the tanks in layers corresponding to their original position.

The crops were seeded in the tanks and in the surrounding plots at the same time, so that the plants in the tanks had the same protection as plants in a field. The grain and grass crops were grown at the rate of 20 plants per tank, which was approximately the same rate as used in the field. An excess of seeds was planted to ensure a full stand, and the surplus plants removed. The tank crops were protected from damage by hail or sparrows by the use of wire screens. The screens did not prevent rain from reaching the soil in the tanks, for a rain gauge placed under one of the screens checked in its readings with a similar gauge in the open a few feet away. The screens undoubtedly shaded the crops to some extent, but their influence on crop growth was too slight to be noticed.

The tanks were weighed at seeding time, as regularly as possible each week afterwards, and at harvest. The difference between the initial and final weights indicated the water lost from the soil through evaporation, and through transpiration by the plants. Intermediate weights gave an idea of the rate of use

of water by the crop. The water lost from the soil, added to that which fell as rain, constituted the total water used to produce the crop. No account was taken of the weight of the crop in these calculations, for the crop from such a small area was not sufficient to cause any appreciable difference in the weight of the tank.

The use of soil contained in tanks as a method of studying soil moisture is subject to criticism for several reasons. The soil had been moved, stirred, and thoroughly aerated to a depth of five feet, and all columnar structure destroyed. The soil column was out of contact with the surrounding soil, and the movement of moisture was restricted. The percolation of water beyond the five-foot depth and the upward movement of water from lower depths was prevented. The effect of these factors upon the productive capacity of the soil is difficult to state.

The first season the tank crops were not equal to those in the small surrounding plots. The lower yield may have been the result of some of the factors mentioned, or because the moisture conditions in the tanks were not as favourable, owing to a loss of moisture during the process of filling. Subsequent grain crops grown in the tanks were equal or superior to those in the surrounding plots.

Equal success cannot be claimed for the first experiments with corn and sunflowers, for normal development was not possible in tanks only 15 inches in diameter. To overcome this defect, tanks having double the surface area and a depth of 5 feet were installed.

The use of soil contained in deep water-tight tanks has provided a convenient means for the study of moisture changes in cropped and fallow land under the climatic conditions of southwestern Saskatchewan.

DISTRIBUTION OF SOIL MOISTURE

The distribution of moisture in summer-fallow which had been cropped in alternate years, and in stubble which had been cropped for four successive seasons, is shown in Table 3. The samples were collected in the fall, following a rainfall of 0·75 inches.

TABLE 3—DISTRIBUTION OF MOISTURE IN SUMMER-FALLOW AND STUBBLE LAND IN THE FALL, FOLLOWING A RAINFALL OF 0·75 INCHES

Depth of sampling	Stubble land	Summer-fallow land	Depth of sampling	Stubble land	Summer-fallow land
	%	%		%	%
1st foot	18·63	23·63	7th foot	13·43	15·46
2nd "	9·33	16·39	8th "	13·99	14·28
3rd "	8·79	19·82	9th "	14·62	14·54
4th "	13·15	15·87	10th "	14·40	15·28
5th "	10·79	13·39	11th "	14·63	14·26
6th "	12·49	13·37			

The effect of the rainfall just preceding sampling is evident in the samples collected from the first foot. Some of this moisture will have penetrated into the second foot by spring. As a rule, moisture from late fall or early spring rains rarely percolates deeper than 24 to 30 inches into stubble land. The previous crop on the stubble land used most of the available moisture from the

second and third foot. The increased moisture content of the fourth foot indicates that the plant roots did not extend to this depth. The summer-fallow land shows an increase of moisture extending down to the fourth foot. This depth will vary according to the class of soil and amount of precipitation. In the tank experiments, percolation was restricted to 5 feet, but from evidence available it would appear that this depth was exceeded only in seasons of higher than average rainfall.

The figures in Table 4 were secured from soil samples collected in the fall of 1929 from areas that had been broken in 1921 and subjected to different crops and cultural treatments.

TABLE 4.—INFLUENCE OF DIFFERENT CROPS AND CULTURAL TREATMENTS ON THE TOTAL MOISTURE CONTENT OF FIELD SAMPLES COLLECTED IN THE FALL.

Depth of sampling	Prairie	Alfalfa	Wheat stubble	Summer-fallow
	%	%	%	%
1st foot	8·41	9·47	7·47	17·65
2nd "	6·78	7·97	8·35	19·75
3rd "	8·70	6·31	7·72	14·15
4th "	7·86	6·22	6·40	10·13
5th "	6·52	5·48	5·98	11·34
6th "	6·30	5·31	5·02	14·50
7th "	7·52	6·20	4·36	19·48
8th "	9·28	6·14	5·79	15·85
9th "	11·56	6·71	6·22	13·56

These figures show that the native grass used all of the annual precipitation, and kept the subsoils approximately dry to a depth of 7 feet. The deep-rooted alfalfa plants, which were 6 years old at the time of sampling, used practically all of the soil moisture to a depth of at least 9 feet. The wheat stubble represents an area that had been seeded each year to an annual grain crop. None of these crops was deep rooted. The dry subsoil under this area must represent a condition that existed at the time of breaking in 1921. The continuous cropping has used all of the annual precipitation, preventing penetration into the lower depths. The summer-fallow samples were taken from the edge of a roadway that was kept free of weeds by cultivation, but never seeded. The moisture present represents an accumulation over a period of years.

There was no evidence in the above samples of any appreciable upward movement of soil moisture by capillarity.

SOIL MOISTURE AND CROP ROTATIONS

Some of the rotations which were started in 1923 have been continued until the present time. These include the common 2- and 3-year rotations of fallow and wheat, and a 7-year rotation containing wheat, brome grass, fall rye, and corn. Wheat was also grown continuously in one set of tanks. The results of the above experiments have given information on the amount of water used by the different crops, the amount of moisture in the soil at harvest time, and the moisture conserved by the summer-fallow.

In these experiments, the tanks and border plots were seeded to the appropriate crop at the same time the fields were sown. Care was taken to keep down all weed growth throughout the season, except in some special cases where it was desired to determine the influence of weeds. No attempt was made to control soil moisture, the crops being dependent on the natural precipitation.

These experiments brought out various facts that were more or less applicable to all crops. In so far as soil moisture was concerned, all the grain crops thoroughly exhausted all the available moisture within reach of their root systems, no moisture being left for succeeding crops. Moisture was not stored while the crop was growing, but only after the crop had been removed. In the case of stubble land, there was a period of approximately 9 months in which moisture might be stored. With summer-fallow, this period was approximately 21 months. Wheat seeded on summer-fallow invariably yielded higher than wheat on stubble land, chiefly because of the greater amount of available moisture.

The figures in Table 5 deal with wheat grown on summer-fallow in three rotations, consisting of: a 2-year rotation of fallow and wheat; a 3-year rotation of fallow, wheat, and wheat; and a 4-year rotation of fallow, wheat, wheat, and oats. The figures include rainfall during the growing period; water taken from the soil, that is to say, the water present in the soil at seeding time that was utilized by the crop; the yield of grain; and the relationship between the total water used and the weight of grain and straw combined. The information presented is an indication of soil moisture and crop relationships as they occur under field conditions, for natural conditions were simulated as closely as possible.

TABLE 5.—YIELDS OF WHEAT ON SUMMER-FALLOWED LAND AND WATER USED BY THE CROP

Year	Precipitation seed time to harvest (inches)	Water from soil (inches)			Yield (bushels)			Pounds water used per pound total crop		
		2-yr. rot. *	3-yr. rot. *	4-yr. rot. *	2-yr. rot.	3-yr. rot.	4-yr. rot.	2-yr. rot.	3-yr. rot.	4-yr. rot.
1923	14·02	3·12	3·96	3·97	43·0	49·5	46·7	585	526	541
1924	7·73	6·79	6·10	5·20	36·9	46·9	47·3	484	452	416
1925	3·65	8·52	7·98	8·16	34·6	32·8	29·1	471	482	502
1926	6·00	9·73	8·24	5·18	54·0	44·9	30·9	396	409	456
1927	7·48	8·40	9·03	9·97	62·7	61·4	64·9	408	419	420
1928	7·63	10·36	9·77	9·10	64·8	59·9	61·7	331	364	322
1929	6·12	5·18	5·61	7·81	22·5	23·9	24·1	545	550	574
1930	4·83	5·65	4·55	4·47	28·2	25·5	21·8	434	443	466
1931	4·89	3·10	3·89	....	17·1	20·1	....	694	691	....
1932	7·89	3·89	3·77	....	27·3	25·9	....	563	585	....
1933	4·31	6·24	6·86	....	28·0	29·1	....	595	574	....
1934	5·89	5·34	5·42	....	28·3	20·2†	....	503	698†	....
1935	8·16	3·57	3·73	....	31·8	32·4	....	478	520	....
Average, 1923–1930	7·18	7·22	6·90	6·73	43·3	43·1	40·8	457	456	462
Average, 1923–1935	6·81	6·15	6·07	....	36·9	36·4	....	499	516	....

*2-year rotation—fallow, wheat.
3-year rotation—fallow, wheat, wheat.
4-year rotation—fallow, wheat, wheat, oats.
† Crop injured by soil drifting.

Table 5 shows that the wheat yield on summer-fallowed land was approximately the same, irrespective of the crop sequence preceding the summer-fallow period. There was also a fairly close agreement in the amount of water used to produce each unit of total crop. The average water requirement was approximately 500 pounds for each pound of dry matter. This figure varied from year to year, being higher in years of low yield and lower when the crop was above the average. The water required to produce each pound of grain was approximately 3 times as great as for each pound of total crop. This amount varied from 956 to 2,182 pounds. When plants experience difficulty in securing moisture, the yield is reduced and the amount of water used for the production of each unit of crop is materially increased.

Examination of the tabulated figures in Table 5 indicates that on several occasions the crops secured a greater proportion of their water from the soil than from the rainfall. Such spreads are in reality greater than the figures indicate, because part of the seasonal rainfall was lost by evaporation.

Table 6 deals with wheat following a previous crop of wheat, in the following rotations: wheat, continuously; a 3-year rotation of fallow, wheat, and wheat; a 4-year rotation of fallow, wheat, wheat, and oats.

TABLE 6—YIELDS OF WHEAT ON STUBBLE LAND AND WATER USED BY THE CROP

Year	Precipitation seed time to harvest (inches)	Water from soil (inches)			Yield (bushels)			Pounds water used per pound total crop		
		Wheat continuously	3-yr. rot. *	4-yr. rot. *	Wheat continuously	3-yr. rot. *	4-yr. rot. *	Wheat continuously	3-yr. rot. *	4-yr. rot. *
1924	7·73	+0·65	0·04	0·27	9·7	12·4	14·6	1,085	920	856
1925	3·65	4·94	4·40	4·04	19·0	16·2	14·0	551	597	596
1926	6·00	2·32	2·15	1·92	16·3	14·7	13·3	626	719	770
1927	7·48	5·42	5·22	5·50	42·0	44·0	37·6	475	476	497
1928	7·54	1·53	1·02	1·45	18·9	21·7	24·3	497	452	442
1929	5·70	0·75	0·47	0·16	8·5	8·4	6·8	813	795	845
1930	4·80	1·80	1·65	1·77	11·5	11·4	10·0	663	607	705
1931	4·89	+0·08	none	....	5·1	5·4	....	1,342	1,169	....
1932	9·23	1·06	0·55	....	10·8	8·9	....	784	923	....
1933	4·31	3·14	2·67	....	13·6	11·0	....	884	948	....
1934	5·89	1·85	1·96	....	11·2	11·3	....	784	732	....
Average, 1924–1930	6·13	2·30	2·14	2·16	18·0	18·4	17·2	673	652	676
Average, 1924–1934	6·11	1·88	1·83	....	15·2	15·0	....	773	759	....

* 3-year rotation—fallow, wheat, wheat.
4-year rotation—fallow, wheat, wheat, oats.

The plus (+) sign indicates that more soil moisture was present at harvest than at seeding time. A protracted dry spell sometimes produces such severe wilting in the crop that subsequent rains fail to restore growth and the moisture from these rains is not utilized.

It is shown in Table 6 that the stubble crop required approximately 770 pounds of water for each pound of dry plant material, as compared with approximately 500 pounds of water used by the crop on summer-fallow. The amount of water required by the stubble crop to produce one pound of grain varied from 1,090 to 3,685 pounds, which was about three times as great as the amount required for each pound of grain and straw combined. This ratio was approximately the same as for the summer-fallow crop. The summer-fallow crop required from 30 to 60 tons of water for each bushel of grain produced, while the stubble crop required from 35 to 90 tons of water for each bushel of grain. One inch of rainfall over an acre is equivalent to 113 tons of water. This amount is equal to the water required for the production of 1·88 to 3·77 bushels of wheat on summer-fallow or 1·25 to 3·21 bushels on stubble land.

The stubble crop was much more dependent on the seasonal rainfall for its moisture, securing a much smaller percentage from moisture stored in the soil. The previous summer-fallow crop had practically exhausted the available soil moisture, with the result that only the moisture conserved from fall and winter precipitation was available for the following stubble crop at seeding time.

Tables 5 and 6 show very clearly the influence of soil moisture on crop production. While the effect of individual showers or the critical periods of plant growth are not indicated, the conditions during the growing season and a comparison of the effect of stored moisture and seasonal rainfall are shown.

RATE OF USE OF WATER

Spring-sown grain crops make no appreciable use of soil moisture until the plants are from three to four inches in height. The rate of use of water gradually increases, under favourable conditions for growth, until a maximum is reached at about the time of heading. This high rate is maintained until ripening sets in, when it diminishes rapidly. The rainfall is not sufficient, as

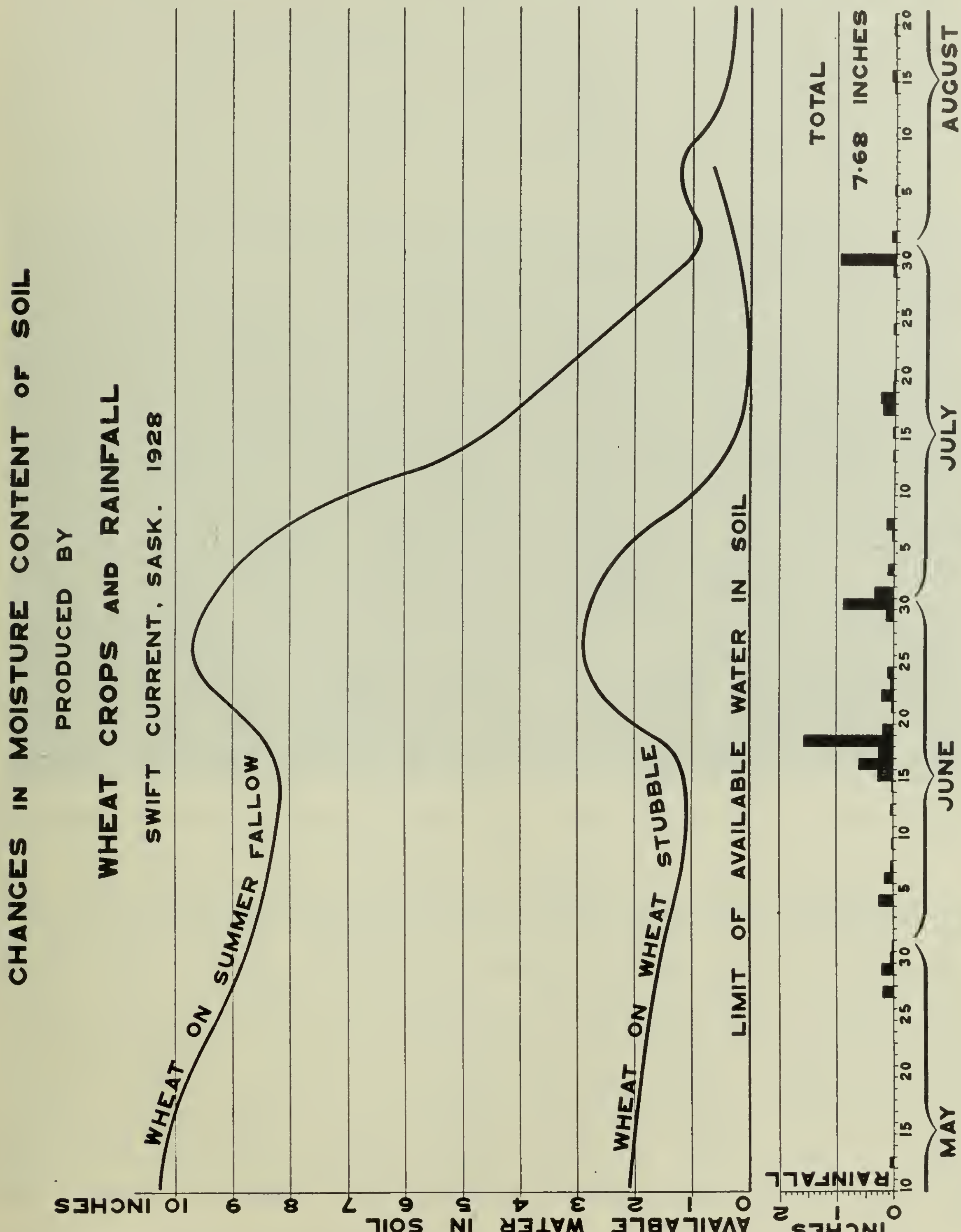


Fig. 4.—Changes in moisture content of soil produced by wheat crop and rainfall.

a rule, to maintain normal vegetative growth, and the plants are compelled to draw upon reserves of moisture present in the soil. A rapid use of soil moisture frequently occurs during periods of strong winds with high temperature and low humidity, factors which stimulate a rapid transpiration of water from living plants. If the supply of moisture is not replenished rapidly

enough by rainfall, plant roots find it increasingly difficult to meet demands for moisture, and wilting may occur. The early heading of wheat is frequently indicative of soil moisture deficiency.

The rate of use of water by wheat seeded on summer-fallow and stubble land is shown graphically by Fig. 4. This chart was drawn from figures secured in 1928. The base line indicated as "Limit of Available Water in Soil" was determined by reference to the total weight of tank and soil during previous seasons. The lowest recorded weight was taken as indicating the point when no available soil moisture was present. The difference between this weight and the intial weight at seeding time represents the total available moisture distributed in the soil. This moisture has been reported as its equivalent in inches of water. Rainfall during the growing season, which represents additional supplies of moisture, is also indicated.

FIG. 5.—Wheat on summer-fallow July 6. No apparent damage from moisture deficiency.

The utilization of soil moisture, in addition to water secured from rainfall, proceeded steadily until June 15. By this time 50 per cent of the available moisture in the stubble land had disappeared. Heavy rains arrested further losses, and even added substantial amounts of moisture to the reserves. With increased growth of the crop, soil moisture disappeared very rapidly. There was an average daily loss of water from the previously summer-fallowed land equivalent to 0·42 inch of rain between July 9 and 16, although the rainfall during this period was only 0·04 inches. The stubble crop had exhausted all available soil moisture by July 21, and at this time growth ceased. Figures 5 and 6 show the condition of the two crops on July 6. Because of diminishing supplies of soil moisture, the stubble crop had fewer leaves and was headed out. The crop on summer-fallow was still growing vigorously, although both were seeded on the same day.

Moisture deficiency at any period of crop growth appears to be reflected in the subsequent yield. According to the results of experiments conducted in Russia, the yield of wheat subjected to drought when the plants were in the shot blade stage was only 50 per cent of that grown under favourable conditions. Wheat subjected to drought when in the heading stage was reduced in yield to 34 per cent, and that in the late milk stage to 77 per cent of wheat

grown normally. At Swift Current the average yield of wheat on stubble land where the full effect of a drought is most likely to be felt, is less than 50 per cent of that from previously summer-fallowed land, although the latter frequently does not furnish adequate moisture supplies.

FIG. 6.—Wheat on stubble July 6, second crop after summer-fallow. Moisture deficiency has caused crop to head out.

INFLUENCE OF SWEET CLOVER ON SOIL MOISTURE AND YIELD OF WHEAT

Included among the crop rotations conducted with soil contained in tanks, was a 3-year rotation of fallow, wheat seeded to sweet clover, sweet clover hay. The sweet clover was seeded with wheat on summer-fallowed land, and failure to secure a stand occurred only in 1930. In this respect, far greater success was secured than that attending similar efforts on a field scale.

Results secured in the experiment with sweet clover are presented in Table 7. The figures include the rainfall during the growing period, the available soil moisture, and the yield of the wheat crop. Corresponding information from a 3-year rotation of fallow, wheat, wheat is included.

TABLE 7.—AVAILABLE SOIL MOISTURE AT SEEDING TIME IN SUMMER-FALLOW FOLLOWING SWEET CLOVER AND WHEAT, AND THE YIELD OF THE SUBSEQUENT CROP.

Year	Precipitation seed time to harvest (inches)	Available soil moisture in summer-fallow		Yield of wheat on summer-fallow	
		After sweet clover (inches)	After wheat (inches)	After sweet clover (bushels)	After wheat (bushels)
1925	3·65	9·70	7·98	35·5	32·8
1926	6·00	6·94	8·24	36·6	44·9
1927	10·67	5·02	5·02	35·9	61·4
1928	7·63	9·74	9·77	63·7	59·9
1929	6·12	6·28	5·61	27·2	23·9
1930	4·83	4·19	4·55	20·2	25·4
Average	6·48	6·98	6·86	36·5	41·4

The average yield of wheat on summer-fallow over a period of 6 years was higher in the standard rotation of fallow, wheat, wheat than in the rotation containing sweet clover. During the season of 1927 when moisture conditions were good, the wheat in the sweet clover rotation produced at the rate of 35·9 bushels per acre as compared with 61·4 in the standard rotation. The ratio of grain to straw was lower in the sweet clover rotation, the grain comprising 29·3 per cent of the total crop as compared with 40·4 per cent in the other rotation. In 1928, when growth conditions were perhaps the best during the period, the yield of wheat from the sweet clover rotation was higher than in the standard rotation. The proportion of grain to straw was approximately the same in both cases, and practically equivalent amounts of water were used by both crops in the production of one pound of dry matter.

From the evidence available, the inclusion of a crop of sweet clover in the 3-year rotation had no definite effect on the wheat crop grown on summer-fallow following the sweet clover.

GRASS CROPS IN A CROP ROTATION

The 7-year rotation in this series of experiments included 2 years of grass crops. Brome was seeded with wheat following a crop of corn. The brome sod was ploughed up following the cutting of the second hay crop.

In relatively dry seasons the nurse crop became more of a menace than an aid to the grass. The grain usually made more rapid growth than the grass, which was soon subjected to severe competition for moisture by the nurse crop. Grass plants, which managed to survive this competition, were dependent upon precipitation received after the grain was harvested, for their root systems were unable to penetrate the subsoil which had been effectively exhausted of moisture by the grain crop.

Figures secured in this experiment, relating to the use of water by brome grass, are presented in Tables 8 and 9.

TABLE 8.—THE USE OF WATER BY BROME GRASS—FIRST YEAR HAY CROP

Year	Precipitation spring time to harvest (inches)	Water from soil (inches)	Yield of hay dry weight (tons per acre)	Pounds water to produce 1 pound of hay dry basis
1924	4·60	2·20	0·58	1,340
1925	2·07	5·72	1·47	556
1926	3·98	0·82	0·48	1,127
1927	7·30	4·80	1·17	1,177
1928	5·86	+1·76	0·37	1,274
1929	4·95	+0·05	0·38	1,452
1930	4·40	1·77	0·46	1,525
1931	3·46	2·00	0·47	1,305
1932	6·26	+2·70	0·61	661
1933	4·23	1·69	0·60	1,117
1934	5·28	2·08	0·50	1,870
1935	4·88	0·90	0·70	935
Average			0·65	1,195

NOTE.—A plus (+) sign indicates that the soil at harvest contained more moisture than in the spring. This is an indication that because of difficulties in securing moisture, the crop had ceased growth before it was harvested and rains had failed to revive it.

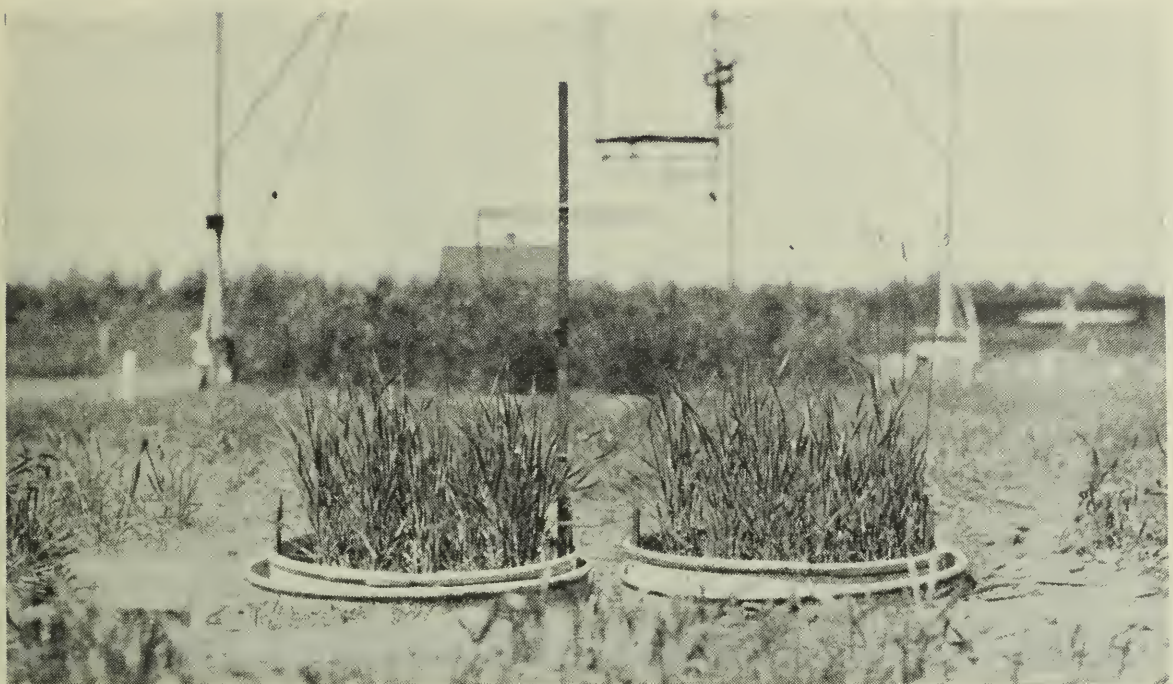


FIG. 7.—Brome grass seeded previous year with wheat. First year hay crop 1928.

FIG. 8.—Brome grass, second year hay crop 1928. Second year crop has made more efficient use of moisture.

TABLE 9—THE USE OF WATER BY BROME GRASS—SECOND YEAR HAY CROP

Year	Precipitation spring time to harvest (inches)	Water from soil (inches)	Yield of hay dry weight (tons per acre)	Pounds water to produce 1 pound of hay dry basis
1924	8·50	1·60	2·10	530
1925	2·07	5·27	1·65	520
1926	Crop	winter	killed	1925–1926
1927	3·94	1·40	1·32	437
1928	5·86	+0·46	1·32	459
1929	4·95	1·72	0·73	1,039
1930	4·40	1·89	0·71	1,003
1931	3·46	2·20	0·45	1,419
1932	6·26	+1·95	1·20	409
1933	4·23	0·63	0·70	793
1934	5·28	2·04	0·72	1,150
1935	4·88	0·86	1·11	600
Average	....	....	0·93	760

(See note after Table 8).

The first year hay crop required 1,195 pounds of water for each pound of hay (Table 8) as compared with 760 pounds of water used by the second crop. This would indicate that longer stands of grass might, under the prevailing climatic conditions, be more economical than those of relatively short duration.

Considered from the standpoint of total dry matter produced, the figures in Table 6 indicate that the wheat crop on stubble land used approximately the same amount of water for each pound of dry matter as the second year brome crop.

Satisfactory yields of hay were secured in only a few instances. On a field scale, very indifferent success accompanied attempts to secure even a stand of such crops. It is reasonable to expect that grass crops seeded alone on summer-fallowed land free of weeds, or land containing ample supplies of available moisture, would return correspondingly higher yields. It does not appear, however, that grass crops can be introduced into a crop rotation where they are compelled to compete with the more rapid growing cereals. The comparative growth of grass crops typical of these experiments is shown in Figures 7 and 8.

CORN AND SUNFLOWERS IN ROTATION WITH WHEAT

Reference has been made to the fact that corn and sunflower plants did not have sufficient space for normal development when grown in tanks 15 inches in diameter. In order to overcome this difficulty, tanks of the same depth but 21 inches in diameter were used.

The larger tanks permitted a normal growth of both corn and sunflowers, but this caused no marked difference in the amount of water used by the plants. The amount of water used for each unit of crop produced is reported in Table 10. In all cases, the crops were grown in rotations in which corn and wheat and sunflowers and wheat were alternated.

TABLE 10.—RATIO OF WATER USED TO CROP PRODUCED BY CORN AND SUNFLOWERS GROWN IN TANKS 15 AND 21 INCHES IN DIAMETER

Year	Corn		Sunflowers	
	Tanks 15″ diameter	Tanks 21″ diameter	Tanks 15″ diameter	Tanks 21″ diameter
1926	404	393	617	697
1927	748	653	610	616
1928	416	496	549	494
1929	826	1,112	1,137	1,271

Corn is generally considered to be economical in the use of water. In these experiments corn produced a fairly large amount of fodder in proportion to the water consumed, but also used practically all of the available soil moisture. Sunflowers required more water for each unit of crop, and also reduced the moisture content of the soil to a lower percentage than the corn crop.

Table 11 shows the influence of both corn and sunflowers on soil moisture and the yield of the following wheat crop. Similar information in regard to wheat seeded on summer-fallow has been included. These figures show that

TABLE 11.—WATER TAKEN FROM SOIL AND YIELD OF WHEAT FOLLOWING CORN, SUNFLOWERS AND SUMMER-FALLOW

Year	Tanks 15 inches in diameter						
	Pre-cipitation spring to harvest	Wheat after corn		Wheat after sunflowers		Wheat after summer-fallow	
		Water taken from soil	Yield of grain	Water taken from soil	Yield of grain	Water taken from soil	Yield of grain
	(inches)	(inches)	(bushels)	(inches)	(bushels)	(inches)	(bushels)
1925	3·6	4·5	14·94	3·2	6·33	8·0	62·10
1926	6·0	3·7	25·12	2·2	14·74	8·3	43·20
1927	7·5	6·1	46·06	0·7	27·87	8·5	63·30
1928	7·7	6·9	53·40	0·1	19·75	9·8	62·15
1929	6·0	0·6	9·52	0·0	5·87	5·5	23·23
	Tanks 21 inches in diameter						
1926	6·0	4·1	25·45	2·6	19·80		
1927	7·5	3·0	37·38	6·1	38·95		
1928	7·7	6·3	49·55	1·1	19·80		
1929	6·0	2·0	14·64	0·9	8·08		

the yield of the wheat crop following corn or sunflowers was much less than the yield following a standard summer-fallow. The yield after sunflowers was less than after corn, which is in keeping with the information on the amount of moisture in the soil following a crop of sunflowers or corn.

From the figures available, it is evident that the use of corn or sunflowers as summer-fallow substitutes is not advisable in the drier portions of the prairies.

THE SUMMER-FALLOW

Approximately fourteen and one-quarter million acres of land are summer-fallowed every year in Western Canada. This practice is intended to control weeds and conserve moisture in the soil. Weed control is complementary to moisture conservation, as actively growing weeds quickly use up soil moisture. In addition to the conservation of moisture and the opportunity afforded to destroy weeds, the summer-fallow helps to store plant food in a form readily available to the plant. In sections where rainfall is not abundant, the practice of summer-fallowing is undoubtedly fundamental to successful grain production.

The summer-fallow is by no means a modern institution, but has come down through the ages. The practice apparently was not always for the purpose of conserving moisture, as the ancient injunction—" Break up your fallow land and sow not among thorns "—suggests the use of the fallow as a means of weed eradication. European countries used the fallow for this purpose for a long time, although at present root crops, or other crops requiring frequent cultivation, answer the same purpose more economically.

The use of the summer-fallow as a means of conserving moisture in Western Canada appears to have been more or less the outcome of pure chance. Alexander Ross in his book, " The Red River Settlement, its Rise, Progress, and Present State," mentions under the date of June 10, 1852, " On finding my crops falling off greatly, I tried the fall ploughing and summer-fallowing to some considerable extent, and it generally answered so well that I became anxious to see it introduced throughout the colony." It appears from this that Ross recognized the value of the summer-fallow but not as a means of moisture conservation.

During the Riel Rebellion of 1885, horses were in great demand to haul supplies for the troops. As a result, Angus Mackay, later Superintendent for many years of the Dominion Experimental Farm at Indian Head, Sask., was unable to plough and seed a considerable area of stubble land early enough to escape the possible fall frosts. The land was ploughed, however, and received a few cultivations during the season to keep down the weeds. The following year proved to be very dry and crop failures were general everywhere, except on the land fallowed during the previous year.

The significance of this experience was not ignored. In his report of 1889 to the Director of Experimental Farms at Ottawa, Angus Mackay wrote: " Our seasons point to only one way in which we can in all years expect to reap something. It is quite within the bounds of probabilities that some other and perhaps more successful method may be found, but at present I submit that fallowing the land is the best preparation to ensure a crop." With this practice in general use on the prairies, the recommendation now appears to be unnecessary. The seasons have not changed, and as the more successful method has not been evolved, the summer-fallow will undoubtedly continue to hold its place as long as wheat forms the principal crop.

Substitute crops have occasionally been suggested as a means of overcoming one of the main disadvantages of the fallow, the fact that the land produces no revenue. This plan is quite feasible where the moisture supply is adequate, and is in general use in humid climates. On parts of the prairie where rainfall limits the yield of crops, a summer-fallow substitute generally means that two poor crops are substituted for one good one.

WATER CONSERVED BY THE SUMMER-FALLOW

In spite of the fact that summer-fallowing is practised for the purpose of conserving moisture, and that this moisture produces substantial increases in crop yields, a surprisingly small proportion of the precipitation is actually conserved during a summer-fallow period. Figures on this subject collected in the Swift Current experiments over a period of 11 years, with soil contained in deep

tanks, are presented in Table 12. The results probably represent the highest efficiency attainable in the storage of soil moisture under prevailing climatic conditions and cultural practices. Rainfall run-off was reduced to a minimum, weed growth was kept down at all times, and the soil was maintained in the best possible condition to absorb water from the rainfall. The tabulated figures record moisture storage during the 3 successive stages of a summer-fallow period, begining with the harvest of one crop and proceeding until the next crop was seeded. The after-harvest period comprises fall, winter, and early spring months, or specifically, August to the following April. Then follows the period May to October, and finally the winter and early spring months, November to April, or a total of 20 to 21 months.

TABLE 12.—WATER CONSERVED BY SUMMER-FALLOW AT DIFFERENT PERIODS OF THE YEAR

Period	Pre-cipitation	Amount conserved		Total pre-cipitation	Total amount conserved	
	inches	inches	per cent	inches	inches	per cent
Aug. 1923–April 1924.......	6·12	1·88	30·7			
May to October 1924.......	11·61	4·80	41·3	22·23	7·46	33·6
Nov. 1924–April 1925.......	4·50	0·78	17·3			
Aug. 1924–April 1925.......	8·40	3·69	44·0			
May to October 1925.......	7·97	1·88	23·6	19·28	5·57	28·9
Nov. 1925–April 1926.......	2·91	none				
Aug. 1925–April 1926.......	7·23	2·80	38·7			
May to October 1926.......	10·51	2·45	23·3	23·26	6·66	28·6
Nov. 1926–April 1927.......	5·52	1·41	25·5			
Aug. 1926–April 1927.......	9·05	4·71	52·0			
May to October 1927.......	13·93	5·80	41·6	25·25	10·51	41·6
Nov. 1927–April 1928.......	2·27	none				
Aug. 1927–April 1928.......	5·51	1·57	28·5			
May to October 1928.......	8·47	3·11	36·7	17·29	4·68	27·1
Nov. 1928–April 1929.......	3·31	none				
Aug. 1928–April 1929.......	4·15	0·38	9·2			
May to October 1929.......	7·76	2·64	34·0	15·67	3·69	23·5
Nov. 1929–April 1930.......	3·76	0·67	17·8			
Aug. 1929–April 1930.......	5·40	2·04	37·8			
May to October 1930.......	9·10	3·50	38·5	16·09	5·54	34·4
Nov. 1930–April 1931.......	1·59	none				
Aug. 1930–April 1931.......	5·85	2·54	43·4			
May to October 1931.......	7·22	2·33	32·3	17·60	5·41	30·7
Nov. 1931–April 1932.......	4·53	0·54	11·9			
Aug. 1931–April 1932.......	6·86	1·32	19·2			
May to October 1932.......	12·14	4·38	36·1	20·73	6·01	29·0
Nov. 1932–April 1933.......	1·73	0·31	17·9			
Aug. 1932–April 1933.......	6·29	1·63	25·9			
May to October 1933.......	10·33	3·63	35·1	18·52	5·26	28·4
Nov. 1933–April 1934.......	1·90	none				
Aug. 1933–April 1934.......	7·92	2·67	33·7			
May to October 1934.......	8·07	1·49	18·5	20·08	4·16	20·7
Nov. 1934–April 1935.......	4·09	none				
Average............	....	....	....	19·63	5·90	29·7

Table 12 shows that the average precipitation for the summer-fallow period of approximately 21 months was 19·63 inches. Of this amount, 5·9 inches or 29·7 per cent was conserved. This figure varied from 20·7 per cent during the 1934 season with a precipitation of 20·08 inches, to 41·6 per cent during the 1927 season when the precipitation was 25·25 inches.

The figures pertaining to the storage of moisture in stubble land just after harvest are of particular importance. During 4 of the 11 seasons, the moisture conserved from August to April was greater than the amount stored during the May to October period. In 6 of the 11 seasons, the percentage conservation during the August to April period was also greater. From the figures in Table 12 the August to October precipitation and the approximate percentage conserved during that period can be calculated. These figures show that from 35 to 94 per cent of the August to October rainfall was stored in the soil. This high conservation was a result of low evaporation and rapid penetration into the unfrozen soil. The above results were obtained on land kept free of weeds. Quite frequently a vigorous growth of Russian thistle takes place after harvest, and all the moisture from early fall precipitation may be used up, thus reducing the total amount of water that might have been stored during the summer-fallow period. Weeds growing on the land in the spring previous to cultivation would have a similar effect on the moisture reserve.

As the figures in Table 12 indicate, winter precipitation contributes very little toward the increase of soil moisture. In 6 years out of 11, with admittedly low winter precipitation, the record shows no increase whatever. The recorded increases in soil moisture as a result of winter precipitation can be attributed to rains or moisture from melting snow received while the soil was in an unfrozen condition. While these observations refer to soil contained in tanks in an exposed position, practically similar conditions were observed in the field.

SOIL MULCH AND MOISTURE CONSERVATION

The effect of a soil mulch on the conservation of soil moisture was determined by the change in weight, over a period of time, of tanks filled with soil. The surface soil in some of the tanks was cultivated after each rain, while the soil in the remainder of the tanks was left undisturbed. The results of this experiment using tanks 60 inches in depth are reported in Table 13.

The data show that the mulched tanks conserved a slightly higher percentage of the rainfall, but the difference cannot be considered significant. In no case was the increase sufficiently great to have any appreciable effect on crop growth. These results tend to confirm other experiments which showed that the prevention of weed growth on summer-fallow had more influence on the storage of moisture than has the type of cultivation.

TABLE 13.—THE EFFECT OF A SOIL MULCH ON THE CONSERVATION OF SOIL MOISTURE

Period	Rainfall inches	Per cent rainfall conserved		Gain in moisture inches
		Unmulched	Mulched	
1931, June 12-Nov. 2	6.68	30.7	32.0	0.08
1932, June 1-Nov. 5	11.38	33.4	36.0	0.30
1933, May 11-July 17	4.23	14.3	18.5	0.18
May 11-Nov. 2	10.33	24.7	26.6	0.20
1935 May 16-Aug. 6	7.09	29.1	34.5	0.39

SUMMER-FALLOW AND WEED GROWTH

The effect of weed growth on the amount of moisture conserved in summer-fallow was determined by subjecting a series of tanks to cultivation at different dates. Ploughing on May 15, June 15 and July 15, without any preliminary treatment was simulated, while some soil was subjected to surface cultivation only. No weeds were seeded in the tanks, but they appeared in greater or lesser numbers each year, particularly when the time of ploughing was delayed. In this experiment, emphasis was placed not so much on the time of ploughing, as on the fact that this operation terminated weed growth on that particular soil. Weed growth was prevented in every case after the land was ploughed.

Results of the above experiment are presented in Table 14. The tabulated gains in moisture cover a period extending from harvest of the previous crop until seeding time of the succeeding crop, or approximately 21 months.

TABLE 14.—MOISTURE CONSERVED BY SUMMER-FALLOW WHEN PLOUGHED AT DIFFERENT DATES—AVERAGES FOR THE SEASONS OF 1928, 1929 and 1930

Treatment of summer-fallow	Water stored in soil
Cultivated only	5·1 inches
Ploughed May 15	4·5 inches
Ploughed June 15	3·6 inches
Ploughed July 15	1·9 inches
Average precipitation	16·3 inches

Under the most favourable conditions only 5·1 inches or 32 per cent of the precipitation was conserved, but where weeds were permitted to grow on the late ploughed land, this figure was reduced to 1·9 inches or 8·6 per cent. Weed growth was responsible for the variations in moisture shown in the table.

In 1928, land ploughed on July 15 not only failed to conserve any of the 5·9 inches of early summer rainfall, but actually lost from the soil 1·18 inches of water which was present in the spring. Figure 9 shows the appearance of the soil before ploughing on July 15, 1928. There were but three weed plants present, one of western rye grass—a weed in this instance, one goosefoot, and one member of the Androsace family. These three plants accounted for the condition outlined above.

TABLE 15.—EFFECT OF PLOUGHING SUMMER-FALLOW AT DIFFERENT DATES ON WHEAT YIELD AND WATER REMOVED FROM SOIL-AVERAGES FOR SEASONS OF 1929, 1930 and 1931

Treatment of summer-fallow	Water removed from soil	Total crop	Grain
	inches		
Cultivated only	4·7	100	100
Ploughed May 15	4·3	89	88
Ploughed June 15	3·3	75	78
Ploughed July 15	1·3	43	47

The tanks of soil used in the experiment on dates of ploughing were seeded to wheat the following spring, and the effect of the previous treatment on crop yield determined. The water removed from the soil and the comparative yield of crop are reported in Table 15.

A comparison of the figures in Tables 14 and 15 shows that the crops used practically all of the moisture that had been stored in the soil during the previous summer-fallow. This fact has been frequently observed in other experiments.

FIG. 9.—Weeds established on land previous to ploughing July 15. The weeds used all the season's rainfall.

The effect of soil moisture on crop yield is also brought out. As the crops received the same amount of rainfall during the growing seasons, the variation in crop yield was caused by the difference in the amount of moisture stored in the soil.

Determinations of moisture present in soil samples taken from field plots in a summer-fallow treatment experiment confirm the results secured with soil contained in tanks, in so far as soil moisture was concerned. The total moisture present in a series of soil samples taken in May, before ploughing, and in a second series taken in August, is given in Table 16. The soil received no preparatory treatment prior to ploughing. The June and July ploughed land supported an appreciable growth of weeds at the time of ploughing, but after this work was performed further weed growth was prevented by cultivation.

TABLE 16.—EFFECT OF TIME OF PLOUGHING ON TOTAL AND AVAILABLE MOISTURE IN FIELD SOILS WHEN WEED GROWTH WAS NOT PREVENTED BY PREVIOUS CULTIVATION—SEASON 1934

Treatment	Moisture in soil				
	Depth of sampling	Sampled in May		Sampled in August	
		Total	Available	Total	Available
	inches	%	%	%	%
Cultivated only	0–6	7·28	0·50	10·52	3·55
	6–12	10·98	3·72	13·74	5·57
	12–24	9·42	3·28	10·54	3·49
	24–36	6·30	0·14	7·00	0·69
Ploughed May 15	0–6	12·61	4·69	12·22	4·18
	6–12	16·82	7·53	15·81	6·70
	12–24	12·93	4·39	15·29	6·30
	24–36	7·78	none	11·73	4·16
Ploughed June 15	0–6	8·99	2·21	10·62	3·47
	6–12	10·97	4·18	13·50	6·30
	12–24	9·27	3·89	6·83	1·60
	24–36	6·04	1·71	3·51	none
Ploughed July 15	0–6	9·70	2·46	8·03	0·60
	6–12	16·47	7·61	9·28	0·83
	12–24	13·37	5·19	8·66	0·24
	24–36	6·39	0·36	6·99	none

The results show in a general way the changes in total and available soil moisture of summer-fallowed land when the time of ploughing was delayed, and there was no previous cultivation to keep down weed growth. The available moisture content was calculated from the "moisture equivalent" of the soil samples, and represents the moisture which can be considered as available for plant use.

There was considerable variation in the texture and moisture content of the samples collected from the field. Because of this fact, they cannot be directly compared as were the uniform tank soils. The general conclusions that can be drawn from the two experiments are similar, in that areas that were ploughed July 15 show a decrease in moisture content when compared with the areas cultivated at an earlier date.

Table 16 shows that the area which was subjected to surface cultivation had a higher moisture content in August than in May. The area ploughed July 15 lost practically all of the available moisture during the same period, as a result of weed growth prior to ploughing.

These results were secured in a season of relatively low rainfall. The figures given in Table 12 show that even in the tank experiments only a small amount of moisture was conserved during the 1934 season. The effect of weed growth on moisture conservation was quite apparent, even during a season when all vegetation was retarded by a lack of moisture.

Prior to 1933, the field areas were all cultivated to keep down weed growth before and after ploughing. Under these conditions, the date of ploughing had no appreciable effect on the amount of moisture conserved, as shown in Table 17. These figures show the available moisture in field samples collected

TABLE 17.—EFFECT OF TIME OF PLOUGHING ON AVAILABLE MOISTURE IN FIELD SOILS WHEN WEED GROWTH WAS KEPT DOWN BY CULTIVATION BEFORE AND AFTER PLOUGHING—SEASON 1932

Treatment	Depth of sampling	Available Moisture	
		Sampled in May	Sampled in August
	inches	%	%
Cultivated only	0–6	0·84	8·38
	6–12	3·30	5·11
	12–24	0·0	4·50
	24–36	0·0	1·76
	36–48	0·0	0·0
Ploughed May 15	0–6	1·88	6·71
	6–12	0·94	4·87
	12–24	0·0	4·83
	24–36	0·0	2·38
	36–48	0·0	0·0
Ploughed June 15	0–6	0·95	8·11
	6–12	3·40	6·42
	12–24	0·0	5·09
	24–36	0·0	0·0
	36–48	0·0	0·0
Ploughed July 15	0–6	0 45	7·74
	6–12	2·40	5·47
	12–24	0·0	6·17
	24–36	0·0	2·70
	36–48	0·0	0·0

in May and August from areas on which weed growth was prevented before and after ploughing. An increase in available moisture is recorded for all samples down to the 3-foot depth. A comparison of Tables 16 and 17 shows that the prevention of weed growth prior to ploughing was more important in the conservation of moisture than the time of ploughing.

WHEAT YIELDS AS AFFECTED BY THE GROWTH OF WEEDS

It is quite evident from preceding discussions that weeds in a crop of wheat may definitely lower the yield of grain. Experiments have shown that the influence of weeds on the yield of grain is probably next in importance to the water supply. In order to secure information on this point, previously summer-fallowed tanks were seeded to both wheat and weeds. Seeds of tumbling mustard, stinkweed, Russian thistle, and wild oats were used. The method adopted was to give the soil a fairly generous seeding of weeds in the fall, and to plant the grain at the usual rate the following spring. The experimental results are presented in Table 18. The yield of wheat from land kept free of weeds is included for comparison.

TABLE 18.—COMPETITIVE EFFECT OF WEEDS ON THE YIELD OF WHEAT—AVERAGE, 1931–1935

Wheat and:	Total water used (inches)	Water to produce one pound of dry material		Comparative weight of		Proportion threshed grain to total crop
		Total crop	Grain	Total crop harvested	Threshed grain	
						%
No weeds	10·7	567	1,500	100	100	36·3
Russian thistle	11·0	447	4,938	131	56	14·0
Stinkweed	10·1	742	2,298	77	65	31·0
Tumbling mustard	11·2	629	2,469	100	75	27·8
Wild oats	10·4	672	2,776	83	53*	19·7

* Wheat grain only.

FIG. 10.—Wheat and Russian thistle. Competition for moisture has caused a large decrease in yield of grain.

The influence of the various weeds on the yield of wheat is brought out very clearly in Table 18. The yield of wheat from the weed-infested tanks varied from 56 to 75 per cent of the yield from the tanks free of weeds. The Russian thistle caused the greatest reduction in the yield of grain. This weed is very efficient in the use of water, as shown by the low water requirement of 447 pounds of water used for each pound of total crop (weeds and wheat). With an approximately equivalent total water supply, the Russian thistle and

Fig. 11.—Wheat and tumbling mustard. Yield of grain materially decreased by weed infestation.

wheat mixture produced 31 per cent more dry matter than wheat alone. Wheat alone required 567 pounds of water for each pound of dry matter, which was a lower rate than any of the other mixtures required.

The lowered wheat yield on the weed-infested tanks is attributed to competition between the two crops for the limited supply of moisture, for the rainfall of the seasons represented was below normal. The number of weeds present were of importance only in that it influenced the degree of competition.

It is evident from these experiments and from field observations that during years of subnormal rainfall the Russian thistle is the most serious menace of our common weeds, and the most effective in reducing crop yields.

Examples of two of the combined wheat and weed crops are shown in Figures 10 and 11. Under field conditions the Russian thistle mixture would prove difficult to harvest, and much loss of grain would be inevitable.

WATER REQUIREMENT OF CROPS

The " water requirement of a crop " is a figure denoting the amount of water consumed in the production of a unit quantity of dry material. It is usually expressed as the pounds of water used to produce one pound of dry plant material. This amount will vary depending upon the conditions under which the experiment is conducted.

While plants may be classified with respect to their water requirement, this does not mean that crops with a low water requirement are necessarily adapted to areas of light rainfall. However, with an equal amount of available moisture and other growth conditions the same, the plant with a low water requirement will be more productive than the plant with a relatively high water requirement, assuming in each case that all the available moisture is used by the crop.

Experiments to determine the amount of water used by crops have been made in various parts of the world. These experiments were planned to discover what effects were produced when crops were supplied with water in varying amounts, care being taken to prevent evaporation from the soil and ensure that all water was consumed by the plants during their growth. It was found that the amount of water used when compared to the amount of crop produced was lowest when a certain quantity of water had been applied. If this quantity was increased, or decreased, the result in both cases was an increase in the water requirement. It was also found that soil fertility, temperature and humidity of the atmosphere, wind velocity, and sunshine, acting in combination, produce marked changes in different seasons.

In calculating the water requirement of any crop, two factors may be secured. One is usually termed the " Evaporation-Transpiration Ratio " and the other " Transpiration Ratio." The Evaporation-Transpiration Ratio is calculated from the weight of the crop produced and the total amount of water used. This water consists of the amount absorbed by the plant together with that lost by evaporation and run-off from the soil. In calculating the Transpiration Ratio, account is taken only of the amount of water actually absorbed by the plant. On this account, the Evaporation-Transpiration Ratio is higher than the Transpiration Ratio. The two factors are alike in one respect. They represent the relative efficiency of various crops in their use of water when the crop is grown under a particular set of climatic conditions.

From the figures secured in the soil moisture experiments at Swift Current, the water requirement of some of the more common farm crops has been determined. This information is set out in Table 19, and also in graphical form in Figure 12, expressed as pounds of water required to produce one pound of dry matter.

TABLE 19.—RATIO OF WATER TRANSPIRED BY CROP PLUS LOSS FROM SOIL BY EVAPORATION TO EACH UNIT OF DRY MATTER PRODUCED EVAPORATION—TRANSPIRATION RATIO

Year	Seasonal rainfall (inches)	Wheat on summer-fallow		Wheat after wheat		Wheat after corn		Wheat after sunflowers		Oats after wheat		Corn after wheat	Sun-flowers after wheat	Brome grass after wheat	Sweet clover after wheat
		Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain				
1924	7·73	460	1,300	953	2,073	....	....	....	....	685	2,633	430	724	1,340[1]	862 1st cutting
															520 2nd cutting
1925	3·65	483	1,384	596	2,000	590	2,035	767	4,197	501	1,115	496	594	606[1]	860 1st cutting
														509[2]	735 2nd cutting
1926	6·00	425	1,249	745	2,173	679	1,983	810	2,100	671	2,423	405	617	1,127[1]	1,610 1st cutting
1927	9·97	421	1,006	487	1,182	458	1,115	486	1,451	452	909	748	489	1,177[1]	696 1st cutting
														437[2]	584 2nd cutting
1928	7·63	339	1,056	447	1,437	373	1,030	496	1,492	532	1,187	416	549	1,274[1]	442 1st cutting
														458[2]	1,011 2nd cutting
1929	4·61	556	1,974	820	3,007	887	2,629	1,080	4,089	1,179	4,725	826	1,137	1,425[1] 1,040[2]	1,267 1st cutting
1930	4·71	448	1,469	656	2,322	824	2,791	763	3,013	627	1,828	655	897	1,525[1]	Failure
Average*	6·33	447	1,348	672	2,028	635	1,930	733	2,723	664	2,117	568	715	1,210[1] 611[2]	956 1st cutting 712 2nd cutting

[1] First year hay crop. [2] Second year hay crop—Brome after Brome.
* Expressed as pounds of water required to produce 1 pound of dry matter.

TABLE 20.—WATER REQUIREMENT OF CROPS—TRANSPIRATION RATIO*

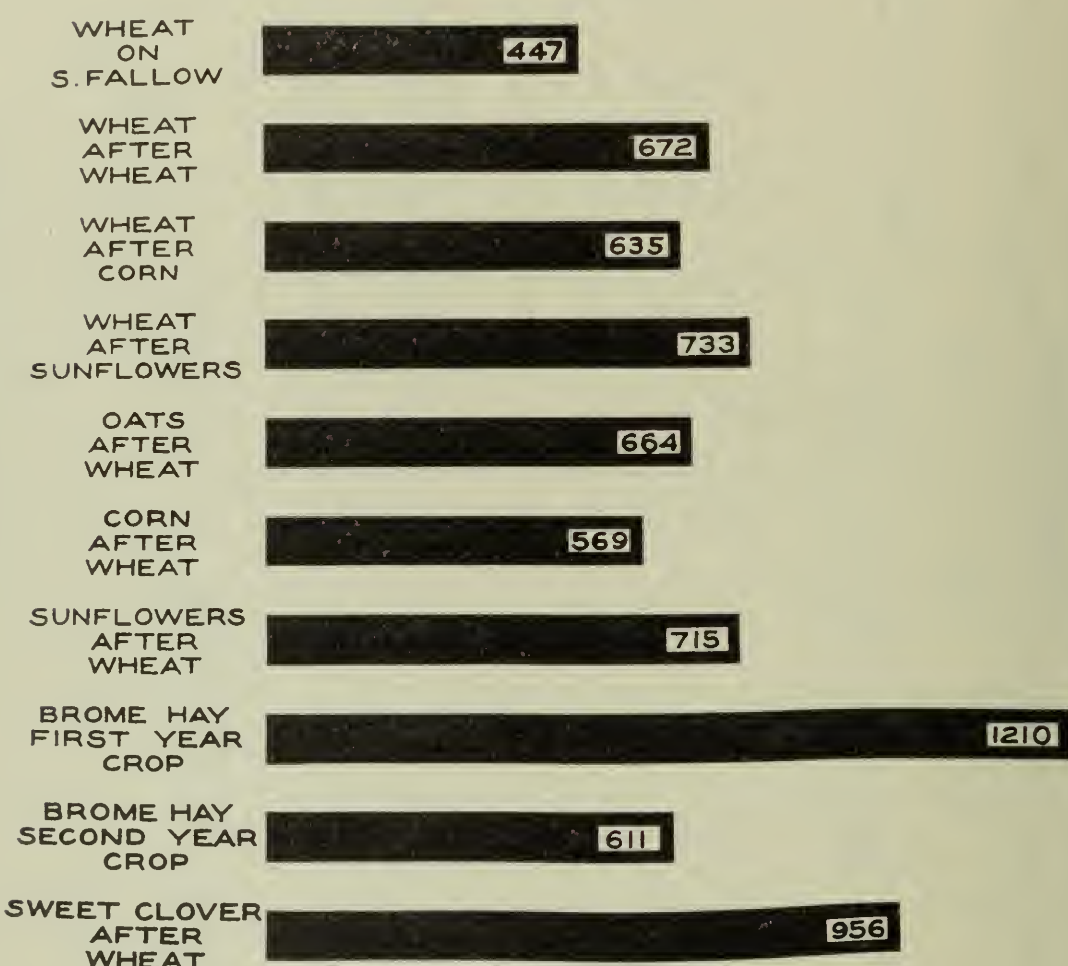
(all crops grown after grain)

Year	Rainfall	Wheat		Oats		Barley		Russian thistle	Stink-weed	Tumbling mustard	Corn	Sun-flowers	Brome grass	Sweet clover
		Grain and straw	Grain	Grain and straw	Grain	Grain and straw	Grain							
	inches													
1924	7·73	324	851	307	897	321	858	166	406	....	174	290	862[1]	1,108[1]
1925	3·65	430	1,152	377	813	411	1,057	209	587	646	231	355	2,033[1]	929[1]
1926	6·00	379	1,077	314	717	298	578	205	309	557	181	368	444[2]	273[2]
1927	9·97	254	589	258	521	279	530	166	538	484	269	294	332[2]	180[2] 257 Two cuttings
1928	7·63	296	777	270	571	257	537	200	576	463	215	422	845[1]	159[2] 189 Two cuttings
1929	4·75	501	1,818	368	951	526	1,429	326	717	571	291	586	317[2]	228[2]
1930	4·71	439	1,085	385	856	320	611	274	571	635	316	384	401[2]	256[2]
Average†	6·35	375	1,050	326	761	345	800	221	529	559	240	386	1,247[1] 374[2]	1,018[1] 220[2]

[1] First season's growth. [2] Second season's growth.
* Ratio of water used to produce each unit of crop. Water used represents that transpired by crop only.
† Expressed as pounds of water required to produce 1 pound of dry matter.

The figures in Table 19 show the amount of water required by various crops to produce one pound of dry matter during the seasons of 1924 to 1930. The wheat crop on summer-fallow was more efficient in the use of water than the stubble crop, having a water requirement of 447 as compared with 672 for the stubble crop. The stubble crops were almost entirely dependent on the seasonal rainfall, which was subject to considerable loss by evaporation. Such losses were included when computing the water used, which gives a high water requirement. It was found that, in all cases, the water requirement for each pound of grain was about three times as great as the requirement for a pound of total crop.

COMPARATIVE WATER REQUIREMENT OF CROPS 1924-1930



The crops grown on stubble land all used approximately the same amount of water for each pound of dry matter. Corn was a little more efficient than the other crops grown on stubble, requiring 568 pounds of water for each pound of crop as compared with 635 to 733 for wheat, and 715 for sunflowers. The second year crop of brome made much better use of the available moisture than the first crop. Sweet clover had a fairly high water requirement, which is characteristic of sweet clover and alfalfa. These results represent fairly closely the conditions that actually exist in the field. From the figures available, a farmer would expect to harvest more total plant material from a corn crop than from any of the other crops, when grown on stubble land.

The figures presented in Table 19 are not directly comparable with those obtained in experiments by other investigators (Table 21). In most water requirement experiments, the object has been to determine the quantity of water actually absorbed by a plant during its growth, care being taken to prevent loss of moisture by evaporation from the soil. In many cases the crop was grown in surface soil only, and the moisture supply was maintained at a constant point throughout the growing period. In the Swift Current experiments the crops have been produced entirely by the season's rainfall together with any available moisture present in the soil. As a rule, the moisture supply at some time or other was deficient, a condition which increases the water requirement.

Figures are presented in Table 20 showing the water requirement of crops grown in soil from which evaporation was prevented during the growing season. The tanks used for this experiment were provided with closely fitting lids, containing holes through which the plants grew. The holes were closed by means of plasticine to prevent the entrance of rain after plant growth had started. Water was added through a hole in the centre of the lid, in amounts equivalent to the rainfall. Water removed from these tanks was all absorbed by the growing plants, and the excess passed off in the process of transpiration. The water requirement of crops under these conditions was calculated from the dry weight of material produced and the total amount of water added, together with that removed from the soil.

The figures in Table 20 show the actual pounds of water used by the various crops to produce one pound of dry matter. These figures represent the Transpiration Ratio as compared to the Evaporation-Transpiration Ratio presented in Table 19.

Wheat, oats, and barley required approximately the same quantity of water (326 to 375 pounds) for each pound of dry matter produced. Corn required 240 pounds of water for each pound of dry matter, requiring less than the cereals, which is in keeping with the results shown in Table 19. The second crop of brome had approximately the same water requirement as the cereals.

Of particular interest is the low water requirement of Russian thistle. This plant is quite prevalent in the drier portions of the prairies, and thrives exceptionally well in the years of low rainfall. Its ability to compete so effectively with the cereals can be explained by the low Transpiration Ratio. Stinkweed and tumbling mustard required approximately 2½ times as much water as the Russian thistle for each pound of plant material. These weeds will withstand more competition from the cereal crops during wet seasons than the Russian thistle, and are also found in districts of higher rainfall, where Russian thistle is absent.

The difference between the Evaporation-Transpiration Ratios (Table 19) and the Transpiration Ratios (Table 20) gives a fairly definite idea of the approximate amount of water lost from the soil by evaporation. The figures in Table 20 were obtained from plants growing in soil from which surface evaporation was prevented. Under these conditions, almost twice as much dry matter was produced with an equal amount of water, as compared with the tanks where surface evaporation was allowed to take place throughout the season. On this basis, approximately 50 per cent of the seasonal rainfall was lost by evaporation. The above statement tends to emphasize the small amount of moisture that is available for the plant during a dry season, and the importance of storing up moisture in the summer-fallow.

The water requirements of various crops, as determined by investigators in different parts of the world are presented in Table 21.

TABLE 21.—WATER REQUIREMENT OF CROPS—TRANSPIRATION RATIO

—	Wheat	Oats	Barley	Corn
(a) Hellriegel, Germany	359	401	297	....
(a) Leather, India	554	469	468	337
(a) Briggs and Shantz, Colorado, U.S.A	507	614	539	369
(b) Thom and Holtz, Washington, U.S.A	432	352	320	249
(c) Tulaikov, Russia	415	430	382	239
( ) Barnes, Saskatchewan, Canada	375	326	345	240

(a) "The Water Requirements of Crops", L. J. Briggs and H. T. Shantz. U.S. Dept. Agr. Bureau of Plant Ind. Bul. 284, 1913.
(b) "Factors Influencing the Water Requirements of Plants", C. C. Thom and H. F. Holtz. Wash. Agr. Exp. Sta. Bul. 146, 1917.
(c) "The Plant in Relation to Water", N. A. Maximov.

THE USE OF WATER BY DIFFERENT VARIETIES OF WHEAT

A study was made of the amount of water used by different varieties of wheat to determine if there was any appreciable difference in their Evaporation-Transpiration Ratio. The various varieties were grown in the same type of soil in tanks, and received only the normal rainfall. Marquis, Garnet, and Reward varieties were grown for 11 years and several other varieties for shorter periods.

The average yield of Garnet wheat was slightly higher and the water requirement lower than for the other varieties. This difference was not considered significant in the case of Garnet and Reward. The lower average yield of Marquis was caused by the low yield in 1932, when this variety yielded approximately only 40 per cent as much as the other varieties. This low yield also raised the water requirement to a maximum for the 11-year period. The low yield in 1932 was attributed to damage by birds. The average yields and water requirement of the three varieties for 10 years, leaving out the 1932 crop, are approximately the same, and show no significant difference. All of the available moisture was used in every case, irrespective of the variety.

Tests, extending over 2- and 3-year periods, of some varieties of durum wheat indicate that they require less water in proportion to the dry matter produced than the varieties of hard wheat.

THE DROUGHT RESISTANCE OF CROPS

Crops can be said to suffer from drought when the loss of moisture by transpiration exceeds the intake of water by the root systems. A combination of climatic conditions, such as high temperatures accompanied by high winds and low relative humidity, which promote rapid transpiration may cause a plant to wilt during the daytime even with ample supplies of water available. This condition may be only temporary, however as such plants may regain their turgid condition during the night.

The following experiment was conducted to determine the reaction of crops to an artificial drought. Various crops were grown in tanks and supplied with abundant moisture until growth was well advanced, when the addition of water was stopped. The limit of available moisture was assumed to have been reached when the daily loss in weight of each tank was one-quarter pound, equivalent to 0·04 inch of water. The plants had all wilted severely at this point. Water

was then added and the reaction of the plants noted. The crops used were: wheat, oats, barley, sweet clover, brome grass, western rye grass, corn and sunflowers.

Wheat, oats, and barley failed to make any recovery after the above treatment. These crops appeared to adjust their growth as the water supply diminished. When the low level was reached, the plants had headed out and usually produced a small quantity of seed. Corn withstood a long period without rain and made a fair recovery after the addition of water. The sunflowers also survived a long period of drought, though under such conditions the yields were very small. Brome grass and western rye grass sent up new shoots after an application of water, and the plants did not appear to have been permanently injured by the treatment. Sweet clover recovered very quickly when water was added.

The term "drought resistance" is generally used to indicate a relative condition. Such crops as grasses and clovers may be said to be more drought resistant than spring seeded cereals, because the former can survive a more extended period of drought. From the farmer's standpoint, drought resistance, or drought endurance, has less significance than the ability of any crop to return the maximum yield under a condition of drought. In this respect, the cereal grains occupy a foremost position in spite of their relatively rapid collapse under a severe drought.

INFLUENCE OF ADDITIONAL MOISTURE ON THE YIELD OF WHEAT

This experiment was set up to determine the effect of an increased moisture supply on the yield of wheat. The 2-year rotation of fallow and wheat was used in one series, and in the other wheat was grown continuously. Soil from a field that had been cropped only a few years, and from another that had been cropped for 20 years previously, was used. The crops were grown in tanks that received the seasonal rainfall plus sufficient additional water to maintain the desired moisture conditions. No fertilizers of any kind were, or had been, added to these soils.

The 10-year averages of wheat yields under the above conditions are reported in Table 22. The yields from a 2-year rotation and continuous wheat, grown in tanks receiving rainfall only, are included.

TABLE 22.—EFFECT OF ADDITIONAL MOISTURE ON YIELD OF WHEAT—10-YEAR AVERAGE

—	Additional moisture	Rainfall only
	bushels	bushels.
Wheat on summer-fallow	61·5	36·8
Continuous wheat	44·5	15·8
Continuous wheat (cropped for 20 years)	30·8	.....

The crop-producing power of these soils under conditions of adequate moisture is shown by the data in Table 22. These figures are much above the yields secured under natural rainfall only, indicating that the lower yields were caused by a lack of moisture rather than a lack of plant nutrients.

The yields are all higher than could be expected under field conditions, for in the tank experiments a uniform stand of grain was secured and all weed growth was prevented. The lower yield on the soil which had been cropped for 20 years previously may have been partly due to a different type of soil, as well as decreased fertility.

The increased yield was accompanied by a decrease in quality of grain when wheat was grown continuously with added moisture. The grain, from the summer-fallow and wheat rotation where additional moisture was added, was approximately the same in quality as that grown with normal rainfall.

THE UTILIZATION OF RUN-OFF WATER

A heavy downpour lasting but a few minutes and covering a comparatively small area is a characteristic feature of many summer showers on the prairies. Frequently the lay of the land is such that there is considerable loss of water by run-off from such showers. The following experiment was conducted to determine the effect of such run-off.

Two adjoining areas 12 feet square were selected on uniform land. One plot had a gentle slope, while the other was carefully levelled and provided with low banks to prevent loss of rainfall by run-off. A rotation of fallow, wheat, and wheat was used. Areas 5 feet square in the centre of each plot were harvested for yield determinations. The yields of the crops grown on these plots are reported in Table 23.

TABLE 23.—YIELDS OF WHEAT FROM TERRACED AND UNTERRACED AREAS

Year	Wheat on fallow		Wheat on stubble	
	Terraced	Unterraced	Terraced	Unterraced
	bushels	bushels	bushels	bushels
1931	20·9	19·1	7·5	6·1
1932	34·2	27·4	9·5	7·0
1933	22·2	13·7	10·4	8·2
1934	27·9	23·2	14·1	6·8
Average	26·3	20·9	10·4	7·0

The results show an increased yield from the terraced area for both the summer-fallow and stubble crops. While the loss by run-off is possibly not high enough to warrant an extensive system of terracing, it might be feasible for a farmer to plough a series of furrows along the contours of gently sloping land, thus preventing to some extent the loss that does occur during periods of heavy rains.

The results of two years' preliminary experiments with alfalfa indicated that the accumulation of run-off water in low areas had a pronounced effect on the yields of alfalfa. The farmer should be able to make use of such accumulation by growing alfalfa in the lower areas which are subject to flooding for a very short period during the spring run-off, or in areas where run-off water may be collected after a particularly heavy shower.

COMMERCIAL FERTILIZERS

The results obtained by the use of commercial fertilizers in the Swift Current district have been somewhat erratic. In some cases an increased yield was obtained, while in others there was no apparent benefit. In many cases the crop showed an increased growth during most of the season, but no apparent increase in yield. This may have been caused by a lack of soil moisture at an earlier period in the plant's life.

In a series of tank experiments where fertilizers were applied to the summer-fallow crop in a fallow, wheat, and wheat rotation, increased yields were secured. There was also some residual effect, as shown by the stubble crop. The results may have been influenced by an increased moisture supply in the tanks, due to the prevention of all weed growth. The results apply to only one type of soil, and as they have not been duplicated in the field, additional work is required before definite recommendations in regard to the use of fertilizers can be made.

SOIL MOISTURE AND CROP FORECASTING

The general effect of rainfall upon the yield of wheat in Western Canada is well known, but as yet rainfall records have not furnished a reliable means for predicting crop yields. As a rule, rainfall higher than average, in dry climates, results in high yields, while in humid climates, rainfall less than the average usually produces the highest yields.

Precipitation, unfortunately, does not occur in any organized order. In some sections the total annual precipitation may appear to follow some roughly defined cycle, but unexpected irregularities make it almost impossible to predict the next season's rainfall with any degree of certainty. Furthermore, as mentioned in the discussion of the water used in the production of a crop of wheat, and according to figures given in Table 5, a large part of the water used by the crops was secured from the moisture present in the soil at seeding time. While this moisture originates from the rainfall, there is no direct relationship between soil moisture and precipitation. Normally, only a fraction of the rainfall becomes soil moisture, and this fraction has varied during the past eleven years from 20·7 per cent to 41·6 per cent of the total.

The matter is complicated further by the fact that a considerable proportion of the moisture in summer-fallowed land may be stored 18 months or more preceding the date of seeding. Of the total water conserved by land summer-fallowed in 1934 at Swift Current and seeded in 1935 to wheat, 64 per cent was stored during the fall months of 1933. The time of arrival of seasonal rains, which cannot be forecasted, exerts a profound influence upon crop yields. There is also the severe competition for soil moisture presented by weeds. It would seem that until such time as a quantitative expression can be given to the amount of available soil moisture, and the occurrence of seasonal rainfall can be predicted with reasonable assurance, the forecasting of crop yields from rainfall figures will remain highly speculative.

SUMMARY

The results of 12 years' experimental work on soil moisture conservation and utilization at the Dominion Experimental Station, Swift Current, Sask., have been presented in this bulletin. The period of time covered has permitted the collection of data for years of low and high rainfall. The major portion of the data has been obtained from crops grown in water-tight tanks, 15 inches in diameter and 5 feet in depth, which were weighed at regular intervals to determine the gain or loss in moisture.

Summer-fallowing has resulted in an average conservation of 29·1 per cent of the precipitation. This figure varied from 20·7 per cent to 41·6 per cent, depending on the time and nature of the precipitation, generally being higher in years of high rainfall. Winter precipitation had very little effect on the amount of moisture conserved, for very little water enters the soil when the ground is frozen. When the soil was dry, moisture from showers of one-quarter inch or less was generally lost by evaporation within a few days and thus did not appreciably increase the amount of moisture in the soil.

The growth of weeds before or after ploughing reduced very materially the moisture conserved by summer-fallowing. When weed growth was prevented by surface cultivation, the time of ploughing the summer-fallow had very little effect on the moisture conserved. Surface cultivation, when it prevented weed growth, was as effective as ploughing and cultivating in the conservation of moisture.

Crops grown on summer-fallow frequently secured more moisture from the supply stored in the soil than from the seasonal rainfall.

The use of corn or sunflowers as summer-fallow substitutes on the open plains is not advisable when considered from the standpoint of moisture conservation. These crops used practically all of the soil moisture, thus defeating one of the principal objects of the summer-fallow.

Wheat grown on summer-fallow required approximately 450 pounds of water for each pound of dry matter produced. Each pound of threshed grain required approximately 1,350 pounds of water. When wheat was grown on stubble land, the water requirement was approximately 670 pounds for each pound of dry matter in the total crop and 2,000 pounds for each pound of grain.

Wheat grown in tanks, where evaporation was prevented during the growing season, used approximately 375 pounds of water for each pound of dry matter in the crop and 1,050 pounds for each pound of grain. The other cereals had a water requirement similar to that of wheat.

Brome grass and sweet clover had higher average water requirements than the cereal crops grown under similar conditions. A noticeable feature with both these crops was that the first cuttings were considerably less efficient in the use of soil moisture than the second cuttings.

Corn was more efficient in the use of water than wheat or oats when grown under similar conditions while sunflowers were less efficient. Corn grown after wheat required 568 pounds of water to produce one pound of dry matter, while the corresponding figure for sunflowers was 715 pounds.

During years of low rainfall, the water required to produce one pound of dry matter was considerably higher than in years of high rainfall. All crops used practically the entire amount of soil moisture available irrespective of the season.

Russian thistle had a lower water requirement than any of the plants studied. This probably explains its ability to compete so successfully with the grain crops during the drier seasons.

Weeds growing in a crop caused a very marked reduction in yield of grain. This is one of the most important causes of reduced yields.

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